the Bell Jar

Vacuum Technique and Related Topics for the Educator & Amateur Investigator

Notes from the Vacuum Shack — No. 21 September 2021

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Bell Jar Safety

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Having acquired a 310 mm bell jar and a means to evacuate it, one issue that was given some thought to, was that of operational safety. With the bell jar drawn down to even a soft vacuum, forces in the orders of half a metric tonne are present at the centre of the base-plate. Obviously these forces are also spread throughout the structure of the (Pyrex) bell jar.

I am not a safety expert, the notes below are based on a strong sense of personal preservation coupled with a yellow-streak, about a mile wide (metric suggestions please). Not very sexy subject, but maybe worth a little thought.

While the vessel has been designed, and fabricated specifically for vacuum service, even the remotest chance of the bell jar indulging itself in a Rapid Unscheduled Disassembly is enough to put the chills through me. Intuitively, there are two obvious risks from such an event; large sharp flying objects, and small sharp flying objects.

When talking to people about containment of the former, I was surprised that several suggestions included the fabrication of an acrylic box, with one end vented. This assembly is then placed over the bell jar. In my humble opinion, this would probably be a very bad idea since any implosion is also likely to also destroy the acrylic, resulting as plastic as well as glass flying objects.

Further research on the subject indicated that a steel mesh cover on a bell jar was a popular solution. The unit in question only has to successfully do its job once; that will be fine.

A safety cage was constructed using 12 x 12 mm steel mesh, 1 mm thick. The main wrap around the circumference has a 60 mm overlap. Where possible, all joins were wrapped over, then soft-soldered. A photograph of the cage is shown on the next page. The overlap is at the front.

Mark Atherton
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21 Aug 2021

A High Altitude Chamber for Biological Studies -
Take Your Pets to New Heights

Steve Hansen

This article originally appeared in Volume 6, Number 3/4. It is presented here with some updates.It also formed as the basis for the Amateur Scientist *column of April 1998, during the period when the column was conducted by Dr. Shawn Carlson.*

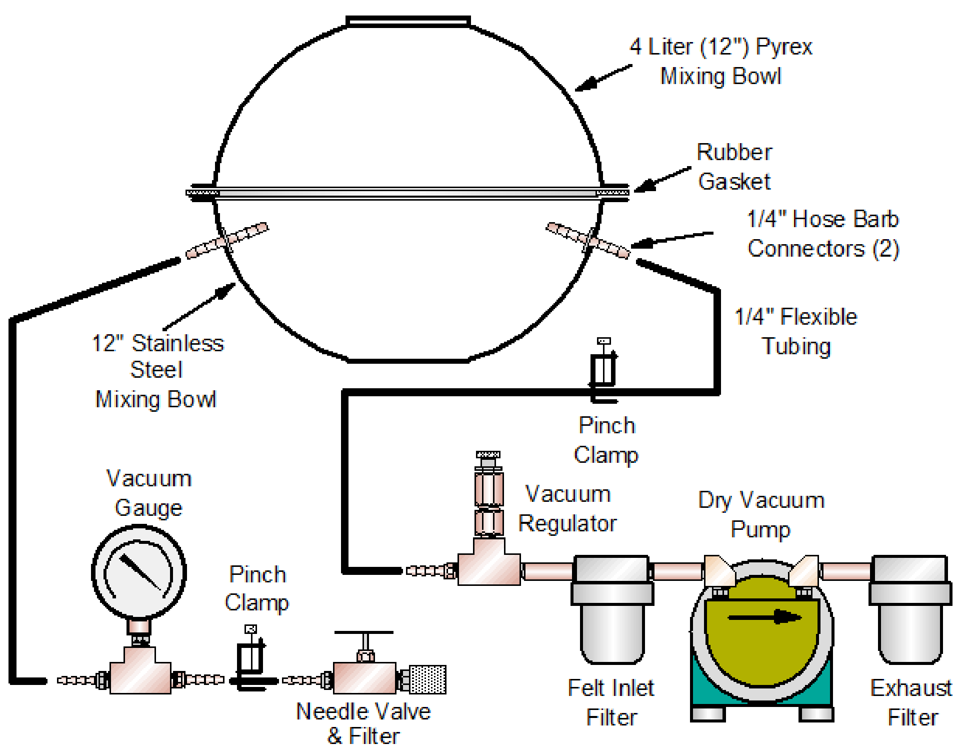
Way back in September of 1965, Scientific American's *The Amateur Scientist* column ran an interesting article on building and using a high altitude chamber. The device, designed by David E. Smucker, a high school student in Wheaton, Illinois, was fairly sophisticated. The chamber itself was made from a 30 gallon steel tank. Three pumps were used to produce and maintain environments simulating altitudes to 30,000 ft. above sea level. One pump, a piston-type refrigeration compressor, was used to evacuate the chamber. Another served to recirculate the air in the chamber through a bed of sodium hydroxide (to control the concentration of carbon dioxide) and calcium chloride (to control the water content). A third pump acted as an emergency backup to the recirculating pump.

The temperature in the chamber was controlled with a heat exchanger coil/fan assembly in the chamber. Water of the desired temperature was circulated through the heat exchanger. Pressure was measured with a mercury manometer and could be automatically controlled to an altitude of 15,000 ft. (400 Torr) using a modified bellows-type pressure control switch. Air was admitted constantly through a leak valve.

Smucker used the chamber to observe the effects of high altitude (10,000 ft.) exposure on the weight and red cell count of albino rats. The experiment ran for 96 days including observation periods. There were 2 control rats and 2 experimental rats. The article detailed the procedure and the results.

Thinking that a simple high altitude chamber might be of interest to some readers of this journal, I put together the simple system that is illustrated in the figure below. The system could be used to study the effects of altitude on plants or small animals such as insects or worms. I don't believe that the controls are adequate for higher forms of animal life.

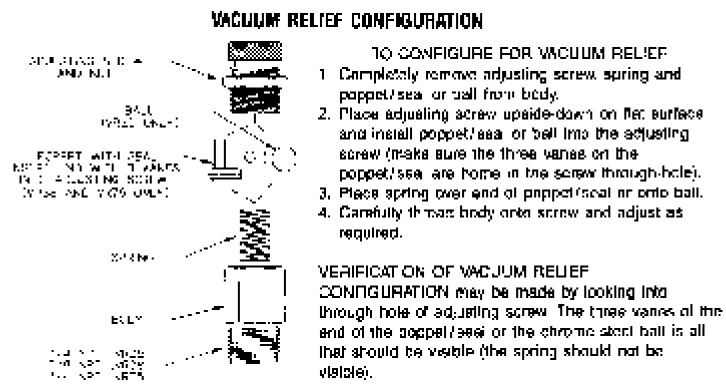
The chamber as originally described is made from two mixing bowls: the bottom bowl is of stainless steel (available from US Plastic Corp. (https://www.usplastic.com/ as catalog number 84104) and the top bowl is a Pyrex 5 liter bowl, available from just about any home goods or hardware store. The bowls are close enough in size that a rubber gasket (sheet stock available from the hardware store) will seal the two together quite effectively.



Holes can be cut in the stainless bowl to permit the incorporation of feedthroughs. I used 1/4" brass hose barbs, epoxied in place. I was a bit concerned about the ability of the steel bowl to withstand vacuum but the only effect was a very slight bowing of the flat bottom. There are probably a lot of other applications where a simple chamber setup like this would be handy.

Vacuum is provided by a dry-vane or diaphragm vacuum pump These are readily available at reasonable cost via eBay. Be sure to get a pump that is rated for continuous service.

Rather than have a pressure switch that maintains pressure by cycling the pump on and off, I used a simple vacuum regulator made by Control Devices and available through local Grainger outlets as catalog number 5Z763. The valve, model number VR25, costs about $11 (2021). Details on this valve are shown in the figure to the right. The valve is a proportional relief valve that must have air going through it to operate. The figure shows the valve setup. You will have to do a bit of juggling between the needle inlet leak valve and the pressure control valve but, once set, the control valve works quite nicely. You will notice that much more air goes through the control valve than through the leak.



I've shown the pressure monitor as a simple 0-30 in. Hg Bourdon gauge. Bear in mind that the gauge and control valve are both atmosphere referenced. If your atmospheric pressure changes due to meteorological conditions or your lab is in Denver, the absolute pressure in the chamber will change accordingly. Also, if you are not at sea level, the reference will be whatever altitude (pressure) you are at. The following table gives a reasonable correspondence (i.e. as good as I could do in looking at a small graph) between altitude above sea level, absolute pressure, and the Bourdon gauge reading.

Altitude (ft.)	Pressure (Torr)	Bourdon Gauge (in. Hg)
0	760	0
5,000	625	5.4
10,000	525	9.4
15,000	425	16.4
20,000	350	13.4
25,000	275	16.4

The dry pump easily got the system up to Mt. Everest altitudes. A good alternative to the Bourdon gauge would be a pocket altimeter.

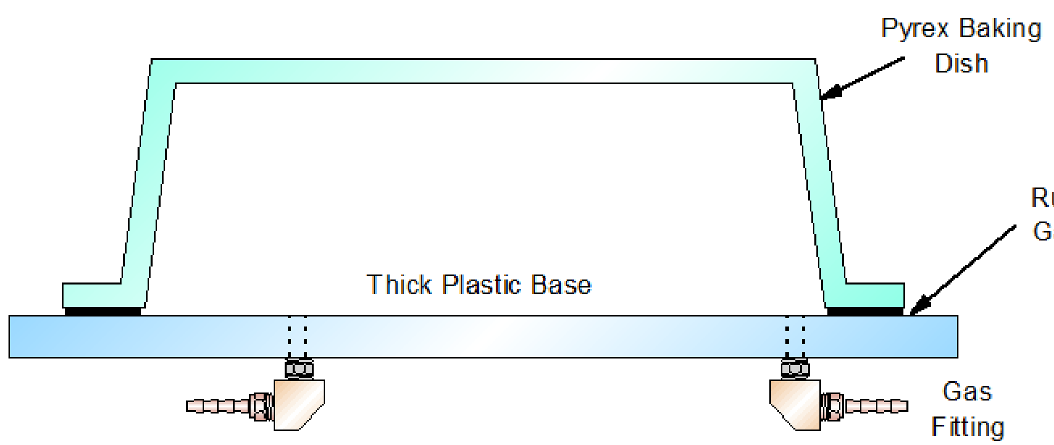
As for regulating the temperature of the chamber to conditions other than ambient, heat lamps above the chamber or a reptile tank heater under it would be workable. If cooler temperatures are desired, the lower bowl could be placed in chilled water.

The incoming air quality can be changed by coupling an appropriate device between the ambient and the needle valve. Driers, bubblers, sources of toxic gases (kidding!), etc. can be placed in series. Liquid nutrients can also be introduced periodically by dipping the inlet into a water solution. This will draw the solution into the chamber. A separate chamber feedthough could also be implemented.

I have shown a couple of pinch valves which can be used to isolate the chamber if it is desired to have a closed system.

A second, atmospheric pressure, chamber might be useful in some experiments. This chamber would be attached to the inlet of the needle valve. Air would first pass through the atmospheric chamber and then through the needle valve into the low pressure chamber. The first chamber would act as a control: same atmosphere, same air flow (mass flow), similar air composition, but at normal pressure.

A possibly simpler chamber might be a Pyrex baking dish that is placed on a thick (3/8 to 1/2 inch) plastic plate with gas feedthoughs. This concept is shown in the figure below.



Recent Advances in Pseudospark E-Beam Research

I had been thinking that research was slowing down on pseudospark devices as I was seeing fewer papers on the topic. Then, a month or so ago, I came across some recent work that has originated largely from Strathclyde University in Glascow, Scotland. The focus has been generally been on the optimization of the electron beam energy from the devices and the use of the beam for the generation of high power microwave (THz) energy.

One of the issues with producing high energy electron beams by a pseudospark source is the rapid collapse of the beam energy following the early, brief (approximately 10-20 ns) cold cathode phase. In the cold cathode phase, the beam energy (in eV) is close to that of the applied voltage to the pseudospark structure. In the ensuing longer duration conductive discharge phase lasting a few hundred ns, the voltage falls and the beam current rises. This might be good for applications such as e-beam ablation but other uses, such as for microwave generation or other energy sensitive applications, a sustained high energy beam is required.

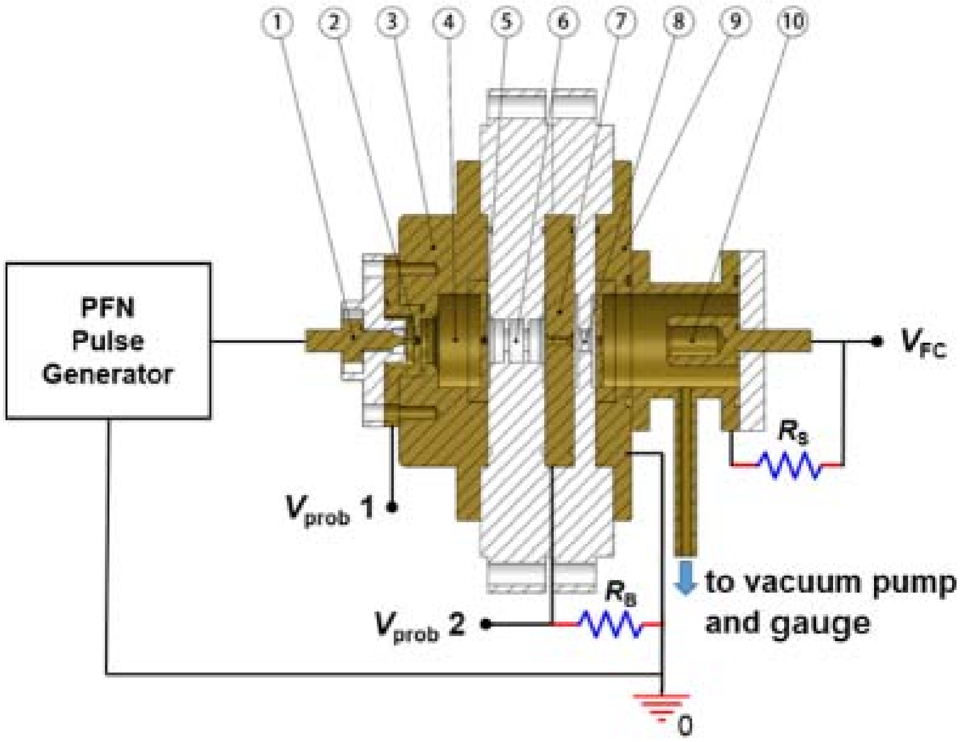
I wrote to one of the authors, Prof. Adrian Cross and he provided some further information and leads.

The basic approach to achieving a high energy beam is to provide an acceleration mechanism at the exit of the pseudospark electrode stack. The time varying energy of the beam exits the pseudospark electrodes and is then accelerated by this supplemental electrode. This generally required two power supplies that are synchronized. A 2017 paper by Zhao *et al*. [1], a collaboration between Strathclyde and Jiaotong University in Xi'an, China, presents a simpler mechanism that uses one pulsed power supply. The arrangement, as shown in the paper, is depicted in the figure on the next page.

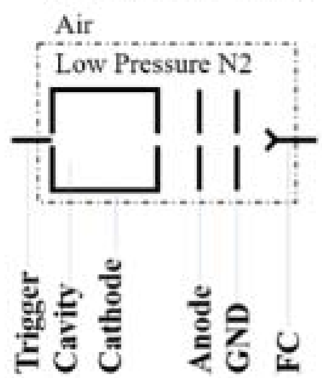
It's a two gap device with the cathode and anode (middle electrode) and then a grounded second anode. The two anodes are connected together by a low value (200 ohms in the described device) resistor. The driver is a Blumlein pulse generator. There is also a trigger electrode in the hollow cathode. The electrode apertures were 3 mm in diameter and the gaps were 16 mm for the pseudospark gap and 6 mm for the acceleration gap. The relatively large pseudospark electrode gap serves to provide a higher beam current. This is based on the results from another paper [2]. The operating voltage was up to about 40 kV and the device worked properly at pressures at or slightly below 10 Pa (70 mTorr).

When pulsed by the pulse forming network, the trigger, pseudospark and acceleration gaps act as a capacitance divider. From the paper "When the high voltage pulse from the PFN generator is applied between the trigger electrode and the grounded flange, the voltage will redistribute on the stray capacitance $c_x \approx 2.5$ pF of the trigger discharge gap, the stray capacitance $c_m \approx 14.2$ pF of the pseudospark discharge gap and the resistor R_B. Because c_x is much smaller than c_m, most of the voltage will drop on the trigger gap before the breakdown of the pseudospark discharge gap. Although within the operating pressure discharge current will flow through the discharge channel and then provides seed electrons to start the pseudospark discharge."

The resistor R_B ensures that the initial voltage drop is only across the trigger and pseudospark gaps. However, once the voltage drops across those gaps during the conductive phase of the discharge, the pulse voltage then appears across the acceleration gap. To work properly, the resistor has to have a resistance that is higher than the characteristic impedance of the pulse forming network. If too high, it will limit the beam current. As noted above, the resistance value chosen was 200 ohms.



Post acceleration structure of the pseudospark sourced electron beam source



Trigger electrode (1), trigger discharge gap (2), pseudospark cathode (3), hollow cathode cavity (4), cathode aperture (5), pseudospark discharge gap (6), pseudospark anode with output aperture (7), post-acceleration gap (8), grounded flange with output aperture (9), Faraday cup (FC) (10). Structures with white and brass colors are insulating and metallic parts, respectively. Illustration reproduced from [1], with permission.

I've now got some ¼, ½ and 5/8 inch thick plastic (Lexan and Teflon) to try some different gap dimensions along with some brass disks for the pseudospark anode. These will be cut to fit my current pseudospark platform.

In addition to the cited references, there are a number of related papers at the Strathclyde portal.

Cited References

1. J. Zhao, H. Yin, L. Zhang, G. Shu, W. He, Q. Zhang, A. D. R. Phelps and A. W. Cross, *Advanced post-acceleration methodology for pseudospark-sourced electron beam, Physics of Plasmas* 24, 023105 (2017). https://pureportal.strath.ac.uk/files-asset/63887434/Zhao_etal_PP_2017_methodology_for_pseudospark_sourced_electron_beam.pdf
2. J. Zhao, H. Yin, L. Zhang, G. Shu, W. He, J. Zhang, Q. Zhang, A. D. R. Phelps and A. W. Cross, *Influence of the electrode gap separation on the pseudospark-sourced electron beam generation*, Physics of Plasmas 23, 073116 (2016). https://pureportal.strath.ac.uk/files-asset/53819305/Zhao_etal_PP2016_influence_of_the_electrode_gap_separation.pdf

Update on My Plasma Activated Water (PAW) Apparatus

Numbers 19 and 20 contained some information on a device for generating plasma activated water using a gliding arc discharge. Number 20 had details on the discharge assembly. As of publication time, I have finished assembling the unit.

Above are two photographs of the assembly. I built it on one of my signature bamboo breadboards. The acrylic chamber sets on a magnetic stirrer. There are four standoffs that serve as feet. These provide clearance for the electronic oil burner transformer that is mounted on the underside. Connections to the GAD electrodes are provided by high voltage silicone insulated wire with alligator clips. To the right side of the breadboard is a 0-30 SLM rotameter for adjusting the gas flow to the GAD electrodes. The rotameter inlet connects to a diaphragm pump (not shown).

Next month's column will have some test results.

Articles of Possible Interest in *Vacuum Technology & Coating* Magazine

September 2010
Getters and Getter Pumps
Getter materials and their uses in electron tubes and pumps.

November 2010
Taming the Pump Down
Vacuum is clean, getting there is the challenge.

May 2013
UHV Compatible Electrical Feedthroughs
From glass to metal seals to the specialty seals of today.

Articles may be accessed at http://vtcmag.com/. Scroll to the bottom of the page to the back issue selection box. Look for my columns and you can probably find other articles of interest in each issue.

End Notes

Current plans for next month include testing of the finished GAD device, an article by Chuck Sherwood on vacuum evaporation and more on either saddle field ion sources or the pseudospark. I also have a flash x-ray device in progress.

As usual, contributions of any complexity are welcome.